United States Patent

Jacobs et al.

[15] **3,662,294**

[45] **May 9, 1972**

[54] **MICROSTRIP IMPEDANCE MATCHING CIRCUIT WITH HARMONIC TERMINATIONS**

[72] Inventors: **Paul H. Jacobs; Robert L. Peay,** both of Schaumburg; **David S. Wisherd,** Mt. Prospect, all of Ill.

[73] Assignee: **Motorola, Inc.,** Franklin Park, Ill.

[22] Filed: **May 5, 1970**

[21] Appl. No.: **34,695**

[52] **U.S. Cl.** ....**333/33,** 333/73, 333/84 M, 321/69

[51] **Int. Cl.** **H03b 7/38, H01p 3/08**

[58] **Field of Search** ....333/84 M, 73 W, 33, 73 S; 321/69

[56] **References Cited**

UNITED STATES PATENTS

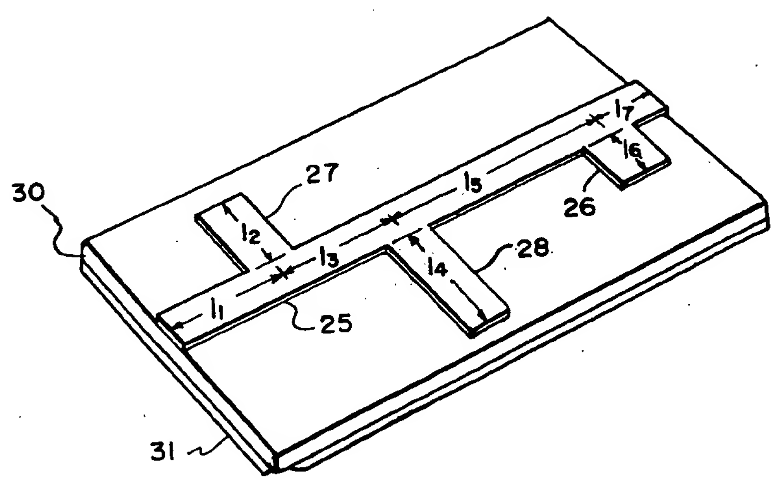
3,343,069	9/1967	Tsuda	321/69
3,402,340	9/1968	Ringereide	321/69
3,345,589	10/1967	Di Piazza	333/73
3,309,626	3/1967	Higgins	333/17
3,292,075	12/1966	Wenzel	321/69

Primary Examiner—Herman Karl Saalbach
Assistant Examiner—C. Baraff
Attorney—Mueller & Aichele

[57] **ABSTRACT**

A microstrip impedance matching circuit has fixed harmonic terminations in the form of a pair of open-circuited stubs, each having a length equal to a quarter wavelength of a different harmonic frequency, connected to the main transmission line to cause the impedance at the harmonic frequencies to be made constant irrespective of the nature of the load impedance at the harmonic frequencies.

3 Claims, 3 Drawing Figures



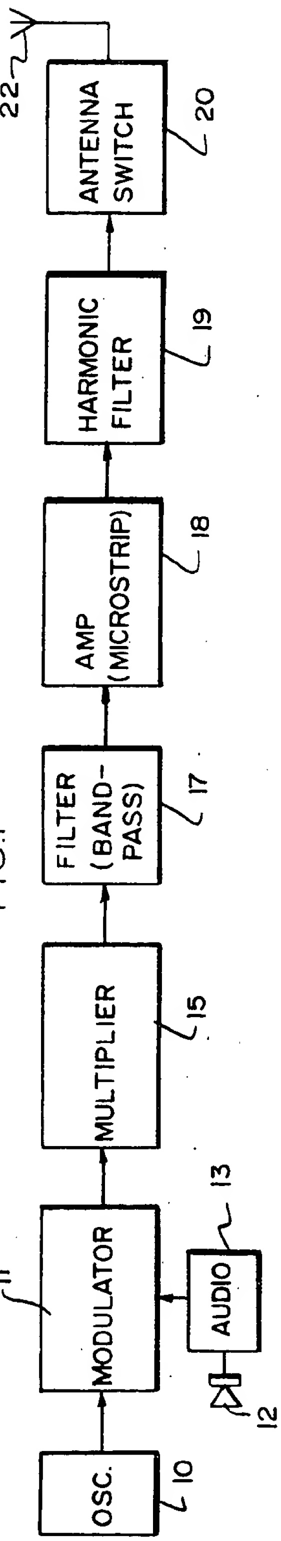


FIG.1

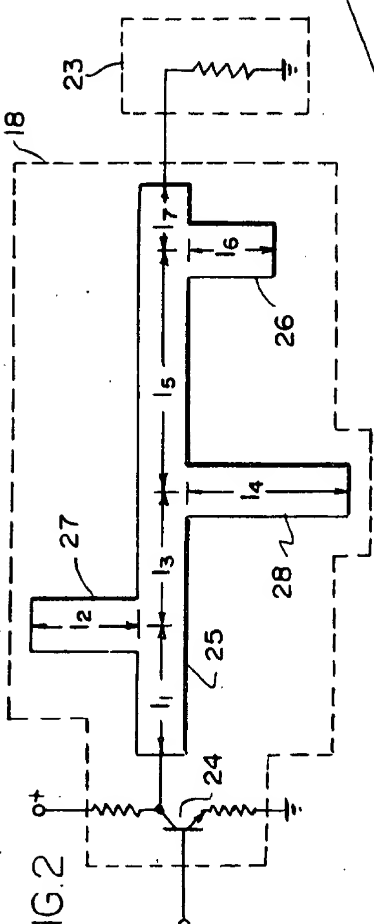


FIG.2

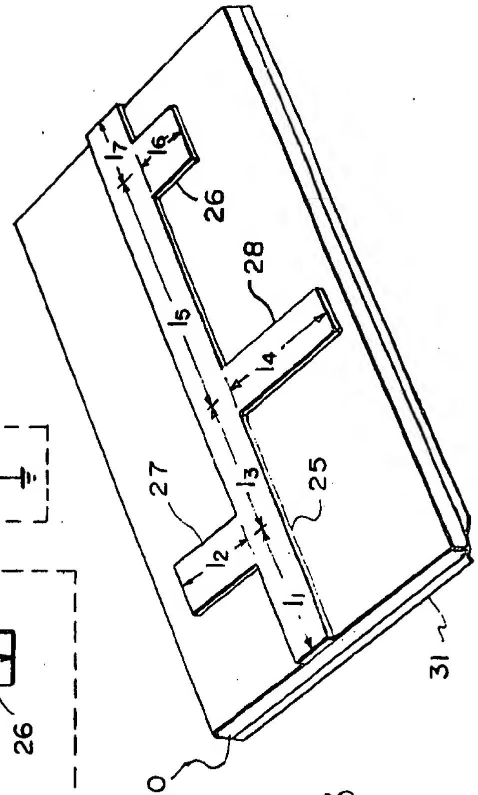


FIG.3

INVENTORS.
PAUL H. JACOBS
ROBERT L. PEAY
DAVID S. WISHERD

BY *Mueller & Aichele*

ATTORNEYS.

MICROSTRIP IMPEDANCE MATCHING CIRCUIT WITH HARMONIC TERMINATIONS

BACKGROUND OF THE INVENTION

Strip line transmission systems or microstrip circuits are commonly used in microwave transmitters and receivers. One use of the microstrip circuits is to provide an impedance matching circuit between the output of an amplifier stage and a load, which may be the input circuit of another amplifier or a band-pass or low-pass filter or the like. Microstrip impedance matching circuits are designed to transform the load impedance to the complex impedance at the fundamental frequency necessary for proper operation of the system. Such devices work satisfactorily so long as the load is a constant pure resistance at all frequencies.

Certain loads, however, present the correct impedance at the fundamental frequency but present reactive terminations at harmonic frequencies. Since RF devices are sensitive to harmonic terminations, the power output and band width of the amplifier can be greatly affected. If the load is mismatched at harmonic frequencies, the power output of the amplifier is low and the response is skewed. It appears that the changing load at the harmonic frequencies shifts the operating point of the amplifier and affects its gain at the fundamental frequency. As a consequence, it is desirable to cause the impedance at the harmonic frequencies to be made constant.

SUMMARY OF THE INVENTION

Accordingly, it is an object of this invention to provide an improved microstrip impedance matching circuit.

It is a further object of this invention to provide harmonic terminations on a microstrip impedance matching circuit, causing the impedance at harmonic frequencies to be made constant.

It is an additional object of this invention to attach stubs to the main transmission line of an impedance matching microstrip circuit, with the lengths of the stubs being selected to reflect short circuits to the harmonic frequencies at the points where the stubs are attached to the main transmission line.

In accordance with a preferred embodiment of this invention, a microstrip impedance matching circuit for coupling an RF amplifier to a load includes a conductive strip having harmonic termination circuit means coupled to the conductive strip for providing a short circuit to signals of at least one harmonic frequency on the conductive strip. More specifically, the harmonic termination is in the form of a quarter wavelength open-circuited stub at the harmonic frequency, with the location of the stub on the conductive strip of the impedance matching network being such as to present substantially an open circuit at the harmonic frequency to the input of the matching circuit and to present a short circuit to reflected signals at the same frequency.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a block diagram of a radio transmitter with which the impedance matching circuit of a preferred embodiment of this invention may be used;

FIG. 2 is a detailed circuit diagram of an impedance matching circuit in accordance with a preferred embodiment of the invention; and

FIG. 3 is a perspective view of a microstrip impedance matching circuit of the type shown in FIG. 2.

DETAILED DESCRIPTION

Referring now to FIG. 1, there is shown an RF transmitter circuit of the type used in a mobile communications unit or the like. The basic operating frequency for the transmitter shown in FIG. 1 is provided by a 30 MHz oscillator 10 which supplies signals at 1 mw to a broad band modulator circuit 11. Audio input signals to be modulated are obtained from a conventional microphone 12 and are passed through an audio amplifier stage 13 to the modulator 11, the output of which also is a 30 MHz signal supplied to a broadband multiplier circuit 15 providing a 450 MHz signal at 1 mw. The signals present at the output of the multiplier 15 are passed through a band-pass filter 17, which may be in the form of a microstrip filter circuit if so desired, and the output of the filter 17 is a 450 MHz signal at 0.5 mw.

In order to provide a signal at sufficient power to the antenna of the transmitter, a microstrip amplifier circuit 18 responds to the output signals from the filter 17 to provide a 450 MHz output signal at 50 watts. This signal is passed through a harmonic filter 19, which preferably is in the form of a microstrip filter, and from the filter 19 to an antenna switch 20, which also may be a microstrip circuit. The output of the antenna switch 20 then is supplied to a suitable antenna 22 for transmission.

In conjunction with a microstrip amplifier 18, it is necessary to provide an impedance matching circuit for matching the output of the transistor amplifier normally used to the input of the harmonic filter 19. The impedance matching circuit must transform the load impedance to the complex impedance at the fundamental frequency(450 MHz) necessary for proper operation of the system.

Referring now to FIG. 2, there is shown an impedance matching network utilizing a microstrip transmission line in accordance with a preferred embodiment of this invention. This network may be included as part of the microstrip amplifier circuit 18 as indicated in dotted lines in FIG. 2. The output of the impedance matching network then is supplied to a suitable load, such as the harmonic filter 19 or someother load such as additional amplification stages, and in FIG. 2. this load is shown as a simple resistor enclosed in dotted lines and identified as load 23.

The output transistor of the amplifying stage which is to supply input signals to the input end of the impedance matching network is shown as an NPN transistor 24, with input signals such as would be obtained from earlier amplification stages or from the band-pass filter 17 being applied to the base of transistor 24. The collector of the transistor 24 is connected to a main impedance matching transmission line or conductive strip 25, the other end of which is connected to the load 23. The microstrip or strip line circuit is formed by attaching the conductive strip 25 to one side of a sheet of dielectric material 30, with the other side of the sheet of dielectric material 30 being covered with a ground plane in the form of a conductive coating 31, best shown in FIG. 3.

To match the impedance of the amplifier represented by transistor 24 to that of the load 23, an impedance matching stub 26 is connected to the conductive strip 25 at the end near the load 23. The dimensions of the stub 26 and the length of the strip 25 (for a given characteristic impedance) may be chosen in accordance with well-known techniques to transform the load impedance to the desired complex impedance at the fundamental frequency. So long as the load is a constant pure resistance at all frequencies, the conductive strip 25 and the stub 26 would be sufficient to provide a satisfactory impedance match.

When a load such as the harmonic filter 19, however, is used, the load presents reactive terminations to signals at harmonic frequencies since the filter 19, while exhibiting a pure impedance at a fundamental frequency, is mismatched at all harmonics of that fundamental frequency. As a consequence, the power output or apparent gain of the amplifier is low and the frequency response characteristics are changed. In order to prevent the impedance matching circuit from being adversely affected by the harmonics of the fundamental operating frequency of the amplifier, open-circuited quarter wavelength conductive stubs 27 and 28 are attached at right angles to the main conductive strip 25 and operate as harmonic terminations or short circuits at different harmonic frequencies. Thus, irrespective of the impedance which is connected at the output or right-hand end of the matching circuit, the harmonic impedance presented to the input or left-hand end is constant.

The harmonic frequencies which constitute the greatest problem are the second and third harmonics, so that the stub 27 is selected to have a length l_3 equal to one-fourth wavelength of the third harmonic frequency and the stub 28 is selected to have a length l_4 equal to one-fourth wavelength of the second harmonic frequency of the fundamental frequency (900 MHz in the example shown in FIG. 1). The stubs 27 and 28 then place a short circuit at these respective harmonic frequencies on the series matching line 25 at the points where the stubs are attached to the line 25, and the position of these short circuit points for the harmonic frequencies may be adjusted to present any desired reactive impedance to the input at the harmonic frequencies. As a result any impedance that is reflected from the load is connected in parallel with these short circuits, so that changes in the load termination at harmonic frequencies cannot affect the input impedance of the matching circuit. Thus, a constant impedance at the harmonic frequencies is presented to the signals on the collector of the transistor amplifier 24.

To provide optimum performance of the transistor amplifier 24, the input impedance at the left end of the conductive strip 25 shown in FIGS. 2 and 3 should match the output impedance of the transistor. For purposes of illustration assume that this impedance is 8.9 + j 9.5 ohms at the fundamental frequency. This is a typical value which may be encountered in applications of the circuit. At the same time the input impedance for optimum performance should be infinite at both the second and third harmonic frequencies. In the construction of the impedance matching circuit, the stubs 27 and 28 may be of any desired impedance, and for the purpose of illustration assume that characteristic impedances of the lengths l_2 and l_4 are each equal to 30 ohms.

In order to cause the input impedance at the third harmonic to be infinite or an open circuit impedance at the input to the strip conductor line 25, the length l_1 must be made equal to the length l_2, namely a quarter wavelength at the frequency of the third harmonic or a one-twelfth wavelength at the fundamental of the input signal. For convenience, the characteristic impedance of the length l_1 also may be 30 ohms.

To provide an open circuit (infinite impedance) for the second harmonic frequency at the input to the left end of the impedance matching circuit conductive strip 25 at the collector of the transistor 24, it is necessary for the point of connection of the stub 28 to the strip 25 to appear as if it were a quarter wavelength away at the second harmonic frequency from the collector of the transistor 24. If the stub 27 were not present, this could be accomplished merely by making the combined lengths l_1 and l_3 equal to the length l_4 which is a quarter wavelength of the second harmonic frequency. The presence of the stub 27, however, must be taken into account since this impedance of this stub is connected in parallel with the impedance of the length l_3 presented to the collector of the transistor 24 at the input end of the conductive strip 25.

From a Smith chart, copyright 1949 by Kay Electric Company, the impedance at the mid-point of the junction of the stub 27 with the main conductive strip 25 must be +j 0.575 (30) or +j 17.2 ohms, and the impedance looking into the length l_2 at the junction point of the stub 27 with the main conductive strip 25 is −j 17.2 ohms.

The impedance of the length l_3 then must be chosen so that when it is placed in parallel with the impedance −j 17.2, it results in a net impedance of +j 17.2, which is the condition providing an open circuit for the second harmonic at the input to the left end of the strip 25. Calculation of this impedance then shows that this parallel impedance must amount to +j 8.6 ohms. If the characteristic impedance of the length l_3 is chosen to be 30 ohms, the short presented by the second harmonic stub 28 at the junction of the mid-point of this stub with the main strip line 25 must be transformed to +j 8.6 ohms on a 30 ohm line or 8.6/30 = 0.286. As a consequence the length of l_3 as determined from a Smith chart is equal to 0.044 wavelengths at the second harmonic frequency or 0.022 wavelengths at the fundamental frequency. As stated previously, the length l_4 is one-fourth the wavelength at the second harmonic frequency, or one-eighth the wavelength of the fundamental frequency, in order to provide a short circuit stub at the second harmonic frequency.

The remaining dimensions l_5, l_6 and l_7 indicated in FIGS. 2 and 3 then must be chosen to provide the desired transformation of the input impedance (8.9 +j 9.5 ohms) to a 50 ohm load at the fundamental frequency. To determine the relative values of the impedances in the branch l_4 and the branches l_5, l_6, l_7 along with the lengths of these branches, it is necessary to start at this amount (8.9 +j 9.5) and move 0.0833 wavelength of the fundamental frequency (one-quarter the wavelength of the third harmonic frequency) toward the load. The load then is 30 (0.28 −j 0.19) or 8.4 −j 5.7 ohms. The load presented by the length l_2 of the stub 27 is $-j$ (1.74) 30 = $-j$ 52.2 ohms. The parallel combination of this impedance and the load presented by the length l_3 between the midpoints of the stubs 27 and 28 must be equal to 8.4 −j 5.7 ohms. Thus, to determine the load presented by the length l_3, the solution is as follows:

$$Z_{l_3} = Z_P\, Z2/(ZP - Z2)$$

Where Z_P = parallel combined load, and $Z2$ = load presented by l_2.

Thus,

$$Z_{l_3} = \frac{(8.4-j5.7)\,(+j52.2)}{8.4-j5.7+j52.2} = 10.3-j4.55$$

Normalizing this to the 30 ohm line, as discussed previously, provides

$$(10.3 - j\,4.55)/30 = 0.344 - j\,0.152$$

moving 0.022 wavelength at the fundamental frequency $C(l_3)$ length on a 30 ohm line gives:

$$(0.365 - j\,0.275)\ 30 = 11 - j\,8.25$$

As a consequence, the parallel combination of the length l_4 of the stub 28 and the remainder of the circuit to the right of the junction of the midpoint of the stub 28 with the main conductive strip 25, which includes the lengths l_5 and l_7, along with the length l_6 of the conventional matching stub 26, must present an impedance of 11−j 8.25. Although the length l_4 is fixed at a quarter wavelength of the second harmonic frequency, the impedance of this length may be arbitrarily selected, with the resulting remaining impedance for the parallel combination being provided by adjustment of the relative dimensions l_5, l_6 and l_7 to obtain the desired matching impedance to the 50 ohm load 23. These adjustments, however, have no affect on the open circuit conditions presented to the input at the left end of the strip line 25 for the second and third harmonic frequencies.

The microstrip impedance matching circuit described may be utilized to couple cascaded amplifier stages or may be used to couple an amplifier stage to a filter stage in the manner described. The stubs 27 and 28 may be placed at other positions on the line 25, if infinite input impedance to these frequencies is not desired. The exact position of the stubs may be adjusted for optimum system performance, and locating the stubs to present a substantially open circuit condition to signals at the harmonic frequencies applied to the input of the impedance matching device is considered to provide such optimum performance. It has been observed that harmonic short circuits provided by the open-circuited stubs 27 and 28 results in a 5 to 10 percent increase in power output over conventional L-C matching circuits, which present a high impedance at the harmonic frequency.

Although the foregoing description has been limited to harmonic impedances in the form of open-circuited quarter wavelength stubs to provide the short circuits at the harmonic frequencies, it is apparent that RF grounded stubs of half wavelengths at the harmonic frequencies also could be used to produce the same results. The quarter wavelength stubs are preferable, because the length of the stubs is shorter, thereby permitting a more compact microstrip layout. In addition, the open-circuited quarter wavelength stubs do not require any additional circuit components. If half wavelength stubs are

used, it is necessary to terminate each of the stubs to ground through an additional capacitor. This results in increased cost and additional assembly operations. Furthermore, the operation of the impedance matching circuit over the band of frequencies immediately adjacent the fundamental frequency is better if the short circuit terminating stubs are kept as short as possible, since the shorter stubs are less frequency sensitive than longer stubs of the type which would be necessitated if the half wavelength stubs were employed.

In the foregoing description, the specific example considered a microstrip line having a characteristic impedance of 30 ohms, which is a conventional line width commonly employed. Different characteristic impedances, however, may be utilized if desired. The impedance matching of the circuit at the fundamental frequency then would be dependent on the characteristic impedance, on the length of the stub 26, and on the impedance presented at the fundamental frequency by the short circuiting stubs 27 and 28. The characteristic impedance, however, of the stubs 27 and 28 is of no significance at the harmonic frequencies since the lengths of the stubs are chosen to present short circuits to these frequencies at the points of attachment of the stubs to the conductive strip 25.

An additional conservation of the physical dimensions of the impedance matching circuit, including the harmonic termination stubs 27 and 28, is effected by placing the third harmonic terminating stub 27 nearest the input end of the conductive strip 25, since a shorter stub is required to terminate the third harmonic at the collector of the transistor 24, the length l_1 must be equal to the length l_2. Thus, if the stub 27 is a short circuit for the third harmonic frequency, the length l_1 is shorter than if the stub 27 were to provide a short circuit at the second harmonic frequency. If such a conservation in the dimensions of the impedance matching circuit is not desired, the stubs l_2 and l_4 shown in FIGS. 2 and 3 could be interchanged, with the length l_1 then being increased to equal the length l_4.

Because the particular characteristics of the microstrip circuitry can be relatively accurately controlled in the manufacturing process consistent reproduction of the device is possible. The predictable characteristics of the microstrip circuitry described above are considered superior to techniques utilizing lumped circuit constants since control of lumped circuit constants is more difficult to implement.

We claim:

1. A microstrip impedance matching circuit for coupling an RF amplifier, operating at a fundamental frequency, to a load including in combination:

a sheet of dielectric material;

a conductive coating on one side of said sheet of dielectric material;

impedance matching circuit means including a conductive strip having an input end and an output end on the other side of said sheet of dielectric material for coupling an amplifier to a load; and

first and second open-circuited stubs connected to and extending substantially 90° from said conductive strip, the length of said first stub being selected to be one-fourth the wavelength of the second harmonic of the fundamental frequency and the length of the second stub being selected to be one-fourth the wavelength of the third harmonic of the fundamental frequency, said first and second stubs being connected to said conductive strip at locations presenting substantially open circuits at said second and third harmonic frequencies to signals applied to the input end of said conductive strip, with said first stub reflecting a short circuit to signals at said second harmonic of the fundamental frequency at the point where said first stub is connected to said conductive strip, and said second stub reflecting a short circuit to signals at said third harmonic of said fundamental frequency at the point where said second stub is connected to said conductive strip.

2. The combination according to claim 1 wherein the one of said first and second open-circuited stubs which is connected to said conductive strip nearest the input end thereof is spaced from said input end by a distance equal to the length of such stub.

3. The combination according to claim 2 wherein said second open-circuited stub is located nearer the input end of said conductive strip than said first open-circuited stub.

* * * * *